THE ABSORPTION OF ULTRA VIOLET LIGHT BY DIFFERENT SOLUTIONS

by

LEONARD PAUL ELLIOTT

B. S., Kansas State Agricultural College, 1923

A THESIS

submitted in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

KANSAS STATE AGRICULTURAL COLLEGE

1929

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PURPOSE

The purpose of this experiment is to determine the absorption of ultra violet light by different solutions; to determine if the characteristic radiation emitted in form of light by the gas of a compound which has been heated to incandescence will be absorbed by a solution of the compound; to determine the maximum wave length of light absorbed by different solutions.

INTRODUCTION

During the past decade a great amount of interest has been shown, by men in the field of biology and other sciences, in the absorption of ultra violet lights by substances of various kinds.

The ultra violet region was discovered by Retter in 1801, when he noted its effect on silver chloride. Discoveries of photochemical effects were numerous during the nineteenth century.

As the limit of the transmissibility of glass is about 300 mu., not until quartz prisms were used was it possible to extend the ultra violet spectrum beyond that point.

By means of fluorite the spectrum was extended to 120 mu. and since gelatine is opaque to the extreme ultra violet wave length, it is necessary to use a specially prepared plate to record these wave lengths.

Much research has been done on the effect of ultra violet light on different compounds and the transparency of different solids.

Very little reference is to be found on research of the absorption of ultra violet light by different solutions.

Some work has been done on the absorption of ultra violet energy by sodium chloride, sodium bicarbonate, sodium carbonate, sodium sulphate, calcium nitrate, sodium phosphate,

and by sodium carbonate.

In this work absorption by water was used as a standard of comparison and the results had very little meaning. Some work was done on the total energy absorbed by a solution by F. B. Pidduck of Queens College, Oxford, on sodium chloride and potassium bromide. Little if any work has been done on the limit of absorption by solutions.

The absorption of light is very closely connected with the emission of light.

Much work has been done upon the emission of light characteristic of a substance, compound or an element and much work has been done on the absorption of light by gases.

Theory of the Emission Spectrum and the Absorption Spectrum of a Gas

When a gas is heated to incandescence, the spectrum consists of bright colored images of the spectroscope slit separated by dark spaces. These images are called bright line spectra. When raised to a sufficiently high temperature, any substance becomes an incandescent gas and gives bright line spectra.

If waves emitted by an incandescent solid or liquid fall upon any non-luminous body, certain of the incident waves are reflected, others are absorbed, and the remainder are transmitted. The spectrum of the transmitted waves has

the appearance of a continuous spectrum from which certain regions have been blotted out. A spectrum of this sort is called the absorption or dark line spectrum of the body which produced the absorption.

The bright line spectra of an element consists of a particular grouping of lines that distinguish that element from all others. When raised to a sufficiently high temperature, any mixture or compound becomes dissociated into the elements composing it, and each component element gives its own spectra independently of all the others. In this manner different substances can be identified by their spectra.

The wonderful sensitivity of the spectroscopic method identification of the components of a body is shown by the fact that $3(10)^{-10}$ grains of common salt gives the characteristic spectra of sodium. $(10)^{-10}$ grains of calcium gives the characteristic spectra of calcium.

From theoretical considerations it can be shown that the waves absorbed by any gas in an excited state are of the same frequency as those which would be emitted if the gas was heated to incandescence.

In agreement with this conclusion it is found that the dark lines of the absorption spectra of a gas occupy the same relative positions as do the bright lines in the emission spectra of the same gas.

To explain the emission of light we must have some understanding of the atom and its make up.

All atom models built of electrons consist of a positively charged nucleus and one or more electrons. The electrons consist of negative charges of 4.774×10^{-10} electrostatic units or 1.59×10^{-20} electromagnetic units and a mass of 8.96×10^{-28} gms.

The mass of the electron is an insignificant part of the mass of the atom (about $\frac{1}{1800}$ in the case of hydrogen) and the volume is an infinitessimal fraction of the atom.

The simplest atom is the hydrogen atom, which consists of a nucleus bearing a single positive charge with one electron. The nucleus of the hydrogen atom is probably the unit of positive electricity called the proton.

Assuming that the hydrogen nucleus is the unit of positive electricity, the composition of the nuclei of other elements can be deduced.

Helium, the second element in the series, has the atomic number two and therefore has a resultant positive charge of two. The mass of helium atom is nearly four times that of the hydrogen atom. So the helium nucleus consists of four protons in the nucleus with two electrons, which makes a resultant mass of four and a resultant charge of two. This nucleus then requires two external negative electrons to neutralize it, which goes to make up the helium

atom.

The mass of an atom is determined by the number of protons present in the nucleus and in a neutral atom the total negative charge of the associated electrons equals the charge of the positive nucleus. The number of electrons in an atom varies from one to 238, depending upon the atomic weight.

In all atoms the electrons are arranged about the nucleus in orbits. The inner orbit is called the K orbit and is complete and stable with two electrons. The next orbit is the L orbit, which is complete with eight electrons, and the element is known as Neon. In the more complex atoms we have the M, N, O, P and Q orbits, which are satisfied with various numbers of electrons.

When an orbit is satisfied, the atom is very stable and inert. If we add one electron to the atom neon, the atom corresponds to sodium. The extra electron is in the M orbit and is known as a Valence electron.

The reason the electrons do not fall into the positive nucleus is assumed to be that the electrons are revolving in the orbits about the nucleus like the planets about the sun and the electrical force of attraction which would cause them to unite is overcome by the centrifugal force of the revolving electron.

Radiation is said to be due to excitation of the atom,

and excitation is due to the transition from one orbit to another or different energy level. If the electron in transition goes from one energy level to a lower, energy is given off, but if the electron in transition goes from one energy level to a higher, energy is absorbed. The least energy given off in transition from one energy level to the next is known as a quantum, which is designated by the symbol hV.

It has been proven by the photoelectric energy law and the photoelectric current law that energy is absorbed only in quanta and energy is given out only in quanta.

To find the amount of energy taken up or emitted at once we must multiply V, which is the frequency of the energy emitted by h, which is 6.554×10^{-27} dn. cm. sec. and known as Plank's Constant.

Then is W is the amount of energy in one orbit or energy level and W_1 is the amount of energy in the next higher energy level, the electron in transition would absorb a quantum of energy $hV = W_1 - W$.

It can be proven that the amount of energy in an orbit is equal to $\frac{2 \pi m e^4}{h^2} \cdot \frac{1}{n^2}$, where n is the number of the orbit, m equals the mass of the electron, e is the charge on the electron in electro-statis units.

Substituting the values of W and W_1 into equation I, and solving for V,

$$V = \frac{2\,\pi i^2\, me^4}{h^3}\left(\frac{1}{(n^2} - \frac{1}{n_1^2)}\right)$$

$$\frac{1}{} = \frac{V}{C} = \frac{2\,\pi i^2 me^4}{h^3 c}\left(\frac{1}{(n^2} - \frac{1}{n_1^2)}\right)$$

Then $\frac{2\,\pi i^2 me^4}{h^3 e}\left(\frac{1}{(n^2} - \frac{1}{n_1^2)}\right) = N\left(\frac{1}{(n^2} - \frac{1}{n_1^2)}\right)$.

This factor N is called Rydberg's Constant and its value equals 109,721 cm.$^{-1}$. By this formula the emission spectrum of hydrogen can be calculated to a very high degree of approximation.

The heavier atoms with which we are concerned have a much more complicated spectrum than in the case of hydrogen. The innermost electrons of the heavier atoms, in making transitions, do not emit ultra violet light or visible light, but the energy emitted is X rays.

The wave lengths emitted or absorbed in which we are concerned are due to transitions made by the valence electrons or those outside the outermost complete shell or ring.

If we take the sodium atom for example, the valence electron oscillates in orbits, the orbits being classified in sequences of increasing size and ellipticity.

The normal orbit of the valence electron is the orbit with the least amount of energy.

The normal orbit of the valence electron is called S, the first of the S sequence. Each orbit is named by a symbol abbreviating the wave number corresponding to it in the series formulae. Thus, 1 S means $\frac{N}{(1 + S)^2}$, 3 P $\frac{N}{(1 + P)^3}$ etc. The sequence of the orbits are as follows:

1 S, 2 S, 3 S, 4 S, 5 S.

1 P, 2 P, 3 P, 4 P.

1 D, 2 D, 3 D.

1 F, 2 F.

Electrons, according to the aximuthal selection principle, can make transitions only from one sequence to the next as they are arranged above.

This limits the energy which can be absorbed by an atom and also limits the energy emitted by an atom.

If the electron is in the 1 S orbit, then the only energy which can be absorbed is the energy made by a transition into a P sequence of orbits. When an electron is out of the normal orbit it is said to be in the excited state. Excitation can be produced by heat, collision, or strong rays of light.

Atoms in the excited state can then absorb a larger variation of wave lengths than those in which the electrons are in the normal orbits.

However, if the electron of the sodium atom is thrown

entirely out of the field of the influence of the nucleus, the atom is called ionized. This makes a very stable atom whose absorption spectrum is very low in the ultra violet light.

METHODS AND PROCEDURE

The quartz mercury arc is the best known artificial source of ultra violet light. Consequently this was one source of light used in the experiment.

This lamp consists of a tube of fused quartz of about 1.5 cm. in diameter and about 30 cm. long. Platinum terminals tipped with tungsten are fused through the quartz at the ends of the tube.

In order to start the luminous discharge, it is necessary that the two electrodes be connected for an instant by tipping the lamps and allowing the mercury to make contact.

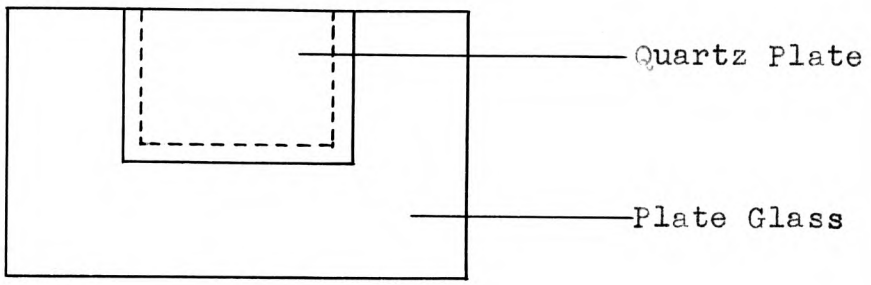
The spectrum for these lamps ranges from 576.9 to 222.5 mu.

The other source of light used was the carbon arc which is made by bringing in contact two carbon electrodes. The carbon arc was used not as a source of ultra violet light but as a crater in which to voliatize different compounds.

The spectrum from this lamp ranged from 576.9 to 180 mu.

Three cells or containers were made with the following thicknesses: 0.5 cm., 0.9 cm., and 5.0 cm. These were made by cutting rectangular pieces out of plate glass. Then quartz plates were cemented over the sides of the glass. The 5.0 cm. cell was made by the same method but walnut wood was used instead of the plate glass.

Quartz Cell



In order that the spectrum of the source, when passed through the cell filled with solution, might be photographed, a spectroscope was used.

The light passes through a narrow slit which is at one end of the collimator on the spectroscope. The light is difracted and passes down the collimator, through a quartz lens which bends the beams into parallel rays.

These pass out of the collimator and strike a quartz prism which again difracts the light. The light then passes through another lens which focuses the light upon a screen or a photographic plate.

In determining the maximum wave length of absorption of

ultra violet light by a solution, a photograph of the quartz mercury arc was made, then a photograph was taken of the light passing through a cell containing the solution. By comparing the two spectra, one could easily determine the lines which had been absorbed.

To determine the lines which were absorbed by a solution from the spectrum of a compound which was heated to incandescence in a carbon arc, a photograph was made of the carbon arc which showed the characteristic lines of carbon. Then the carbon are impregnated with the compound and a photograph taken which showed the characteristic lines of carbon and the compound.

A third photograph was taken with the carbon arc impregnated with the compound, but the light passed through a cell containing the solution. By comparing the three spectra one could determine the lines which were absorbed, the lines characteristic of the compound and the lines characteristic of the carbon.

DISCUSSION

The theory of the absorption of light which has been mentioned is that the only radiations which an atom can absorb are such that have quanta of exactly the right energy to shift the electron from the orbit in which it happens to be to a larger one, with no energy left over.

The amount of energy absorbed is hV, where h is a constant, so the amount of energy absorbed at one time is proportional to V, the wave length of the energy absorbed.

Absorption of light by a dissolved substance means that the atoms within the solution respond to wave length of the light which strikes the atom.

Transparency means that the electrons in the atom are not responding to the wave length of light which is passing through the solution. The electrons which are in the lower energy levels absorb the shorter wave lengths while those in the outer orbits respond only to the longer wave lengths. If an electron absorbs energy and is removed to an orbit of higher energy level, it is then again capable of absorbing another quantum and go into another higher energy level.

The emission or the absorption of ultra violet and visible light is probably due to the electrons in the outer orbits and in the case of the alkali metals the absorption or emission of light is due to the valence electrons or the electrons outside the outer-most complete shell. It has been found that all atoms and ions with the same number of electrons outside the nucleus have similar orbits, --therefore they should absorb or radiate similar wave lengths of light.

In the alkali metals the valence electrons revolve in sequence of orbits and the transitions which electrons are

able to make are limited by a selection principle.

If the valence electrons are not in the normal orbit or the first orbit of the first sequence S, the atom is said to be in the excited state. There are three ways by which an atom may be excited; by heat, collision, or light.

When the electrons are in the normal state, they will absorb only energy of shorter wave length, while if they are in the excited state, the absorption will extend to longer wave lengths. This has been found to be true of sodium vapor, which is not in the excited state; it will absorb an energy which corresponds to that of the 1 S orbit. This has been confirmed. While, if the atom is in the excited state, it will absorb energy of longer wave length.

Much work has been done on the absorption of ultra violet light by gases, but gases are different from solutions. The gaseous molecules do not need a solvent to maintain them in a given space. Their force due to momentum in collision is sufficient for this purpose. In a solution of a solid or a liquid, the molecules are not able to maintain themselves in space, if they are not united by affinity to the molecules of a solvent.

Reactions occur between a compound and water and form various compounds. CaCl with water, for instance, forms what is known as a hydrate, $CaCl_2 \cdot 2H_2O$, $CaCl_2 \cdot 4 H O_2$ and $CaCl_2 \cdot 6H_2O$. This goes to make the study of the absorption

of light by solutions quite difficult.

Ionization

When a salt is put into solution, the molecules are broken down, or dissociated into parts, these parts are called ions and they are known to have a charge because they conduct a current of electricity.

Most of the research on ionization has been done on dilute solutions so the degree of ionization is given in the table for 0.5 normal solution.

The degree of ionization given in the table goes to show that there is no relationship between the degree of ionization and the absorption of ultra violet light by a solution.

Potassium chlorate which absorbed the least amount of light, does not differ but little in the degree of ionization from some of the nitrates although the degree of ionization of the nitrates seems to be less than that of the other compounds but there is no consistency between the degree of ionization and the amount of absorption.

Some normal atoms particularly the halogens are known to possess attractions for the electrons.

The simple ionization of a compound molecule RX may result in the following end products:

(a) $(R)^{+}$ a neutral atom X and an electron.

(b) A positive atom ion $(R)^{+}$ and a negative ion $(x)^{-}$.

(c) A positive molecule ion $(Rx)^{+}$ and an electron.

The chlorides when ionized have a tendency to pick up an electron. The chlorine atom consists of 17 electrons, so if one electron is picked up, this goes to make a very stable inert atom and not subject to absorption only of short wave lengths.

Solubility of Compounds

Most of the compounds used in this experiment were very soluble, with few exceptions. The sulphates used were not very soluble so consequently one would not expect much absorption. The chlorate used was one of the most soluble of compounds and one of the compounds which showed the least amount of absorption of ultra violet light. The nitrates used were all quite soluble but there seemed to be no relationship between solubility of the compounds and the absorptions by the compound, in general, but a sodium chloride which is more soluble than potassium chloride showed more absorption.

Concentration of Solution

The concentration of the solution had a very marked effect upon some solutions as to the limit of absorption of

ultra violet light. When light from a mercury arc was passed through the nitrate solutions, one gram of compound in 10 c.c. of water in a cell of 0.9 cm. thickness, nickel nitrate showed the most marked absorption. (See plate 1, 4, 5).

Absorption by Solutions Used

The nickel nitrate solution possessed a dark green color. This was due to the nickel atom and not to the nitrate, because all the other nitrate solutions used were colorless. No other nitrate solution showed the same absorption as the nickel nitrate, so the marked absorption was due to the nickel and not to the nitrate ion.

This goes to show that in the solution each different ion has characteristic absorption of its own. Something in the solution has been thrown into resonance by the light the other wave lengths pass through. This absorption was in the visible part of the spectrum, so the absorption of this particular wave length must be the reason the solution possesses a dark green color.

Potassium nitrite showed a very marked absorption. (See Plate 1, 3). This absorption was probably due to the nitrate because no other potassium compound showed the same absorption.

The limit of absorption of all the nitrates was the

line 3340 A° or the line 2540 A°. The lines seemed to be heads of absorption bands. The iodides showed a quite sharp absorption band at line A° through a solution 5 cm. in thickness.

The sulphates showed very little absorption and the absorption limit was not sharp.

The chlorides or the sodium chloride showed a sharp absorption band, while the potassium chloride was not so sharp in 5 cm. thickness of solution.

The sodium chloride solution showed more absorption than the potassium solution, probably due to the fact that the sodium chloride is more soluble than the potassium chloride.

The solution of nickel nitrate, a dark green solution, showed an absorption band between the limits of 3700-4200 A° This was probably due to the color of the solution. Color is due to certain wave lengths being absorbed. The color was due to the nickel.

Suggestions for Further Study

Due to the lack of time some of the interesting possibilities which presented themselves could not be taken into consideration.

For instance an increase in thickness of the cell containing the solution would probably show different absorption

than the thickness used.

If some cell could be devised so the solution could be heated and the ions excited by heat the result probably would be different.

If an electric current was passed through a solution and photographs taken through the ends of the cell near the electrodes, some interesting results might be obtained due to the fact that more ions of the same charge would be at the ends.

A solvent other than water could be used such as alcohol. The attraction of the molecules of alcohol surrounding the ions would probably affect the attraction of the nucleus and the electron differently than the molecules of water which surround the ions.

A detailed study of the structure of the ions might be made to determine the reason of absorption.

CONCLUSION

The data collected tends to indicate that a concentrated solution of potassium nitrate absorbed the most of any solution used, and the limit of the absorption band was 3800 A^{o}.

The concentrated solutions of the nitrates had a very sharp absorption band and the limit of absorption was the band 3340 A^{o}.

The more dilute solutions of the nitrates in the cell of 0.5 cm. thickness showed a sharp absorption band at 2540 A^{o}.

The concentrated solutions of the chlorides, acetates, carbonates, sulphates, chlorates showed absorption in the cell of 5.0 cm. thickness, but very little absorption in the cells of 0.5 cm. and the 0.9 cm. thickness.

The iodides showed a sharp absorption band at in the cell of 0.9 cm. thickness.

Nickel nitrate, a dark green solution, showed a marked absorption band between the limits of 3700 A^{o} - 4200 A^{o}.

The shorter wave lengths characteristic of a compound were absorbed by a solution of the compound up to a certain limit. The shorter wave lengths of the quartz mercury arc were also absorbed up to the same limit.

There was no consistency between the degree of ionization and the absorption of a solution.

An increase in the concentration, the thickness of solution remaining constant, caused a marked increase in absorption by some solutions up to a certain limit. An increase in concentration of some solutions showed no increase in absorption. An increase in thickness of solution caused an increase in absorption by all the solutions up to a certain limit.

The absorption in the case of the nitrate solution was

probably due to the NO_3 ion.

The absorption of the nitrite solution was probably due to the NO_2 ion.

Only the shorter wave lengths being absorbed in some cases showed that the atoms were not in the excited state and that the electrons were probably rotating in the inner orbits.

The mathematical predictions or verifications cannot be made in regard to the absorption of solutions due to the complicated structure of the molecules and ions in a solution.

Concentration of Solution	Compound in Solution	Minimum Wave Length of Transmission of Ultra Violet Light Through Solutions — Source of Light: Mercury Arc, Thickness of Cell .3 cm	Mercury Arc, Thickness of Cell .9cm.	Carbon Arc Impregnated with compound, Thickness of Cell .3cm.	Carbon Arc Impregnated with compound, Thickness of Cell .9cm.	Carbon Arc Impregnated with compound, Thickness of Cell .5cm.	Solubility of Compound: No. of gms. of Compound per 100 cc. of water at 18°C.	Degree of Ionization 0.5 Normal Solution
Concentrated	Calcium Chloride	2200	2200	2200	2200	2700	91.00	68.6
"	Calcium Nitrate	3340	3340	3340	3340	3340	56.39	60.9
"	Calcium Fluoride	2400	2400	2400	2400	2540	4.36	
"	Ammonium Acetate	2300	2300	2300	2300	2540	160.00	
"	Potacium Bromide	2300	2300				65.20	76.6
"	Zinc Bromide	2300	2300				82.46	
"	Sodium Chlorate	2200	2200	2200	2200	2540	101.00	
"	Potacium Tartrate	2200	2200				45.00	
10cc.H_2Oto1gm.	Barium Nitrate	2540	2540	3340	3340	3340	9.20	50.4
"	Calcium Nitrate	3340	3340	3340	3340	3340	144.00	77.3
10cc.$H_2O$to.5"	Calcium Nitrate	3340	3340	3340	3340	3340	56.39	60.9
"	Calcium Oxide	2200	2200				0.131	49.0
"	Calcium Acetate	2200	2300	2300	2300	2540	34.7	65.0
"	Calcium Sulphate	2200	2200	2200	2200	2300	.2016	
Concentrated	Strontium Nitrate	3340	3340	3340	3340	3340	82.052	57.9
"	Mercurous Nitrate	3340	3340	3340	3340	3340		70.0
"	Nickel Nitrate	3340	3340	3340	3340	3340	49.06	
"	Sodium Nitrate	3340	3340	2540	3340	3340	87.5	
"	Potassium Nitrite	4000	4000	4000	4000	4000	75.75	
"	Potassium Carbonate	2100	2200	2100	2200	2900	52.5	
"	Sodium Acetate	2200	2300	2200	2300	2540	46.5	
"	Sodium Iodide			2800	2800	3000	78.7	
"	Potassium Sulphate			2200	2200	2800	11.11	
"	Potassium Nitrate			2540	2540	3340	31.6	68.8
"	Sodium Chloride			2100	2100	2700	36.0	77.3
"	Sodium Ammonium Phosphate			2200	2200	2400		
"	Potassium Chlorate			2200	2200	2540	7.22	70.3
"	Calcium Carbonate			2100	2200		.016	

Plate Number 1.

1. Spectrum of carbon arc.
2. Spectrum of carbon arc impregnated with potassium nitrite.
3. Spectrum of carbon arc impregnated with potassium nitrite which shows the absorption due to a solution of potassium nitrite contained in a cell 5 cm. thick.
4. Spectrum of carbon arc impregnated with nickelous nitrate.
5. Spectrum of carbon arc impregnated with nickelous nitrate, which shows the absorption due to a solution of nickelous nitrate contained in a cell 5 cm. thick.

Plate I

Plate Number 2.

1. Spectrum of a carbon arc.
2. Spectrum of a carbon arc impregnated with potassium carbonate.
3. Spectrum of a carbon arc impregnated with potassium carbonate which shows the absorption due to a solution of potassium carbonate contained in a cell 5 cm. thick.
4. Spectrum of carbon arc impregnated with calcium acetate.
5. Spectrum of carbon arc impregnated with calcium acetate which shows the absorption due to a solution of calcium acetate contained in a cell 5 cm. thick.

Plate II

Plate Number 3.

1. Spectrum of carbon arc.
2. Spectrum of carbon arc impregnated with potassium chlorate.
3. Spectrum of carbon arc impregnated with potassium chlorate which shows the absorption due to a solution of potassium chlorate contained in a cell 5 cm. thick.
4. Spectrum of carbon arc impregnated with potassium sulphate.
5. Spectrum of carbon arc impregnated with potassium sulphate which shows the absorption due to a solution of potassium sulphate contained in a cell 5 cm. thick.

Plate III

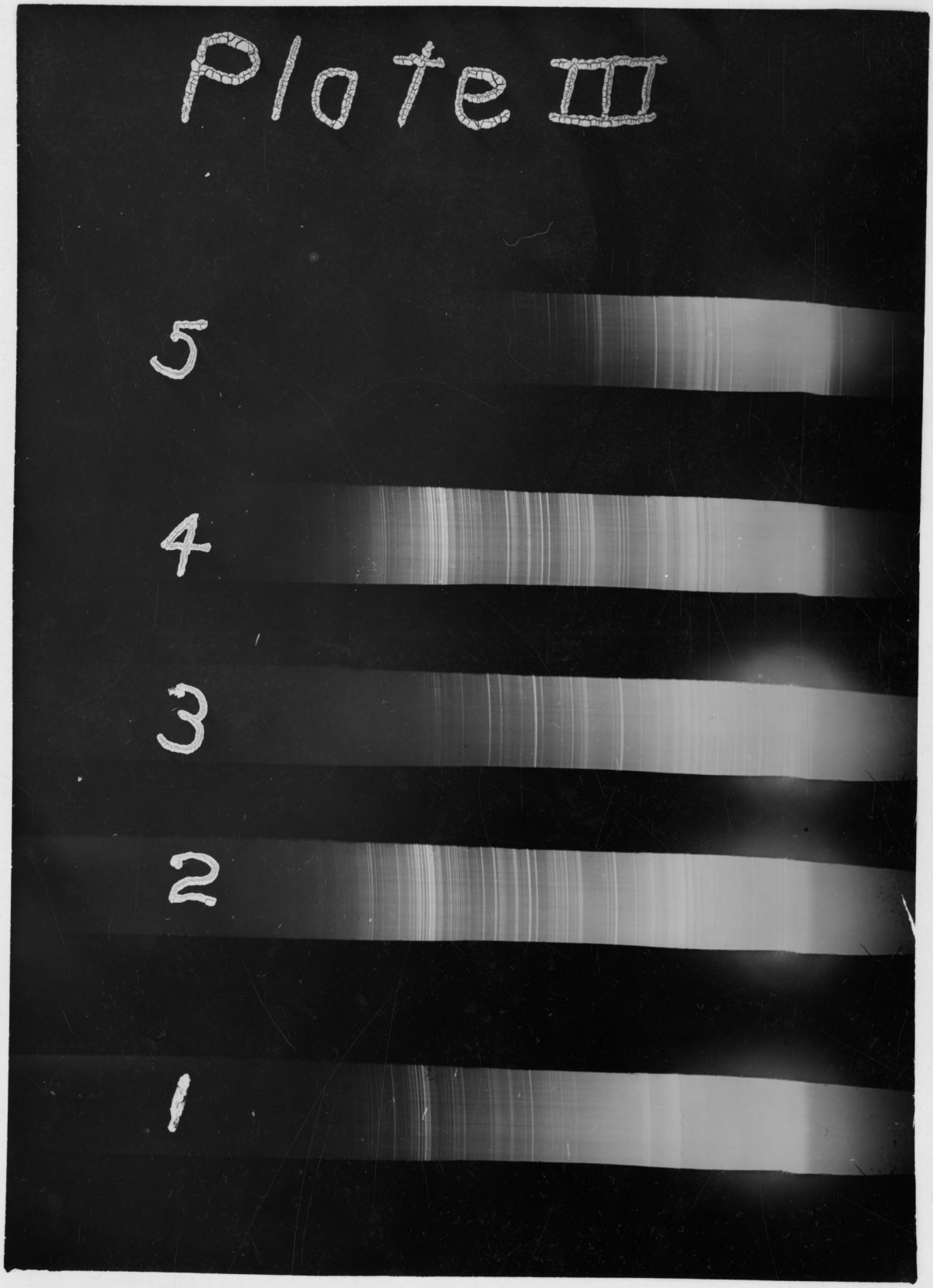


Plate Number 4.

1. Spectrum of carbon arc.
2. Spectrum of carbon arc impregnated with sodium chloride.
3. Spectrum of carbon arc impregnated with sodium chloride which shows the absorption due to a solution of sodium chloride contained in a cell 5 cm. thick.
4. Spectrum of carbon arc impregnated with potassium chloride.
5. Spectrum of carbon arc impregnated with potassium chloride which shows the absorption due to a solution of potassium chloride contained in a cell 5 cm. thick.

Plate IV

Plate Number 5.

1. Spectrum of carbon arc.
2. Spectrum of carbon arc impregnated with sodium iodide.
3. Spectrum of carbon arc impregnated with sodium iodide which shows the absorption due to a solution of sodium iodide contained in a cell 5 cm. thick.
4. Spectrum of carbon arc impregnated with sodium nitrate.
5. Spectrum of carbon arc impregnated with sodium nitrate which shows the absorption due to a solution of sodium nitrate contained in a cell 5 cm. thick.

Plate V

The following shows the wave lengths of various radiations:

	Millimicron	Cm.
Gamma rays	.01	.000000001
X rays	.1	.00000001
Shortest ultra violet	60	.000005
Transmitted by quartz on rock salt	200	.00002
Shortest visible rays	370	.000037
Maximum chemical effect	400	.00004
Violet	400	.00004
Blue	460	.000046
Green	520	.000052
Yellow	560	.000056
Orange	600	.00006
Red	670	.000067
Longest visible waves	760	.000076
Limit of solar spectrum	5300	.00053
Shortest Hertz waves	314000	.0314
Hertz waves in wireless telegraphy and radio	100	10.000(meters)

Symbols to be used:

Unit	Symbol	Millimeter	Relative Wave Length
Angstrom	A^{o}	one tenth million	1
Multimicron	mu, uu	one millionth	10
Micron	u	one thousandth	10,000

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